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A MULTIAGENT SYSTEM FOR EDGE DETECTION AND CONTINUITY PERCEPTION ON OTOLITH IMAGES

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Abstract - **In this paper we present an algorithm for fish otolith growth ring detection using a multiagent system. Up to now, the identification of growth rings, for age estimation, is routinely achieved by human readers, but this task is tedious and depends on the reader subjectivity. One of the major problems encountered during an automatic contour detection is the lack of ring continuity perception. We present an approach to improve this continuity perception based on a 2D reconstruction of rings using a multiagent system. The originality of the approach is to use local edge detection achieved by agents and combine it with continuity perception that active contours allow.**

1. INTRODUCTION

The growth of the otolith is an accretionnary process. The otolith structure is made of alternative opaque and translucent concentric rings. The purpose of growth rings identification is to acquire data on age and growth of fish population. Such data are needed in a great number of biological and ecological studies and to improve stock management. Up to now, this analysis has been mainly limited to a ring count. Ring continuity is a major concept on which readers base their ring detection.

This paper presents an approach to this continuity perception based on the 2D reconstruction of rings.

In 1996 Rodin et al. [9] tried to reconstruct the rings in polar coordinates using a graph construction, by connecting nodes obtained with a primary segmentation of the image. Most of rings were detected on young individuals, but problems were encountered with older individuals, which have very thin marginal rings. In 1997, Benzinou et al.[1] applied a deformable model (Locally Deformable B-Bubble Model) to otolith images. The model was initialised at the growth centre of the otolith and then inflated by computing local forces based on the grey levels and on the global shape of the otolith. Results were encouraging but sometimes drifting of points from the inflated shape could be observed. To tackle this problem, another method inspired by [12] has been proposed in [10]. The external otolith edge is used as a template which is reduced by a homothetic transform centred around the nucleus, which is the otolith growth starting point. As the shape of the ring is forced to be similar to the external contour, drifting of this shape points is thus avoided. Nevertheless the rings shape can only be approximately determined using this method. Therefore the last rings that are very thin and only distinct around the main growth axis (Figure 2) are not well detected.

Another type of methods has recently been set for detecting features in images, which are based on multiagent systems [2] [3] [6] [7] [8]. In 1997 Ballet et al. [8] proposed a multiagent system to detect concentric rings that can be found in natural objects such as tree trunks. Each agent can move around in its environment which is a greyscale image ; its two square-shaped sensors on the pixels of the image allow it to follow light rings (light agents) or dark rings (dark agents) by moving in the direction of the lighter pixels for light agents (resp. darker pixels for dark agents). If the agents have gone over a loop, they can validate their path as a ring. The advantage of this method is to detect very quickly circular structures (a few seconds).

In this paper we present an adaptation of this system to otolith growth ring detection, taking into account high level information (shape of the otolith edge and position of the growth centre).

2. DESCRIPTION OF THE INITIAL MULTIAGENT SYSTEM

As explained above, the system is made up of reactive agents. Each agent has three sensors allowing it to get information about its environment (Figure 1). One unit sensor (one pixel) allows it to locate itself on the image. Two unit sensors are located in front of the agent and distant one from the other. They return the greyscale levels on the part of the image where they are located.

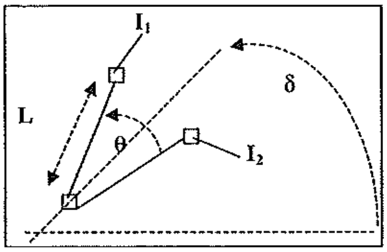

Figure 1 : Agent sensors

A dark agent tries to move where the values returned by the sensors are minimal. A white agent does the opposite. The more important the difference between the two sensors is, the more the agent will deviate. The following equation explains how an agent computes its orientation at step t depending on its orientation at step t-1 and on the difference of intensity between its two sensors. In this equation P is a coefficient which allows to tune this deviation and can be adapted to the length L of the sensors.

$$\delta_{agent}(t)=\delta_{agent}(t-1)+\frac{(I_1-I_2)}{P} \qquad (1)$$

Depending on the data obtained with its sensors and on its internal states, each agent takes decisions. Those internal states are represented by a finite state machine. At the beginning the agent is initialised at random on the image and at the end it can validate a ring if it has gone over a loop or dies if it hasn't found any ring.

Although this detection method is very quick, problems appear when rings are discontinuous, so that agents can't cover the whole ring to come back to their initial position (Figure 2). Only distinct rings are easily detected. Nevertheless agents may have detected an important part of the ring. We will call agents using this behaviour "free agents".

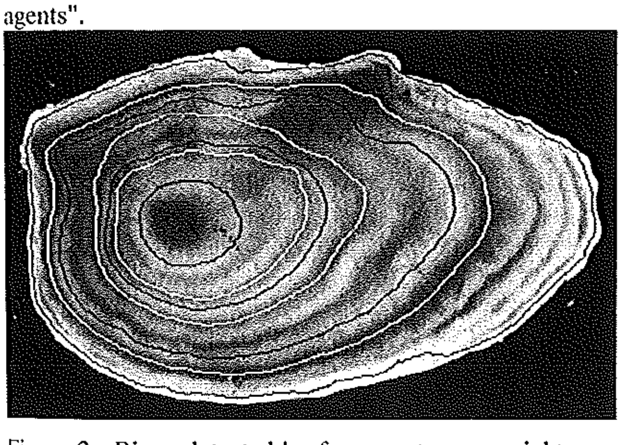

Figure 2 : Rings detected by free agents on an eight year old individual

We present a new way to exploit the behaviour of agents by using an a priori knowledge about otolith growth.

3. USE OF HIGH LEVEL INFORMATION

As other calcified structures (scales, fin rays, vertebrae), the otolith is composed of concentric rings which appear each year. Therefore the shape of the rings is quite parallel to the global shape of the otolith (Figure 2). Otolith growth starts from its centre, which is called nucleus. By comparing the direction of the agent turning around this nucleus with the direction of the contour of the otolith, a decision is taken to recognise whether its path is correct or not.

Some previous steps are necessary to record information concerning the shape of the otolith and the position of its nucleus, and are described below.

A. Preliminary steps

a. The contour of the otolith is detected and its co-ordinates are recorded.

b. Agents with sensors on the image pixels (Ballet et al.[8]) try to detect concentric rings and the co-ordinates of the smallest one are recorded.

c. The nucleus is searched inside the smallest ring. The first white ring is usually well contrasted and easily validated by agents. Then we can search the minimum grey level point in a little neighbourhood around the middle of the ring, which corresponds to the nucleus (Figure 3).

d. Knowing the position of the nucleus and the co-ordinates of points constituting the contour of the otolith, the orientation of little segments composing the contour is computed all around the otolith and this information is recorded on a single image. Thus this image is divided in sectors going from the nucleus to two close points of the contour. In every sector the local orientation of the contour is inscribed (Figure 4).

When this image is created, the agents will have to detect growth rings using these high level knowledge. We propose two different methods to reach this goal : "Directed agents" and "Reconstructed path".

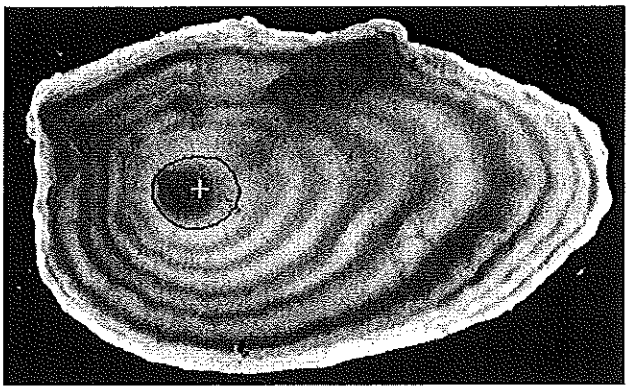

Figure 3: First ring and nucleus detection

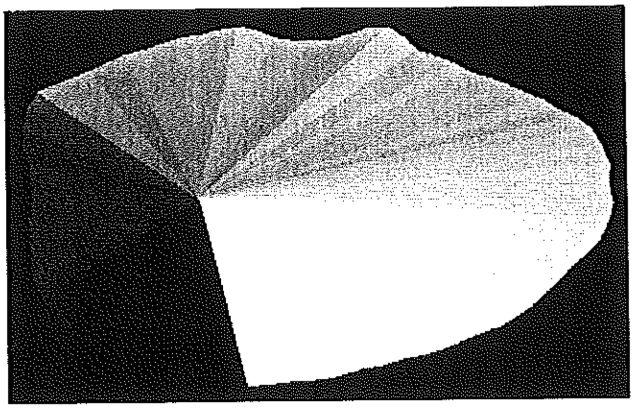

Figure 4: Image of local orientations

B. Directed agents

In this approach, at every step agents make, the orientation computed with the grey levels of their sensors is compared with the orientation of the contour of the otolith in the area where they are located. Equation (2) explains how an agent computes its local orientation δ at step t depending on its orientation at step $t-1$, and on the grey levels of its two sensors (Figure 5). This local orientation is compared with the orientation of the external contour in the area of the image where the agent is located (Figure 6). This angle is proportional with the grey level on the orientation image (equation (3)). The final agent orientation will be computed using both local and high level orientation, as explained in equation (4). In this equation α is a coefficient which varies from 0 near the nucleus to 1 near the external edge. This point expresses the growth of otolith from nucleus to the edge : the shape of last rings is closer to the contour than the shape of first rings. The more the agent is near the otolith edge, the more the constraint is strong. In section 3.D. we will explain how α can be computed using an image of localisation (Figure 12).

$$\delta_{local}(t) = \delta_{agent}(t-1) + \frac{(I_1 - I_2)}{P} \quad (2)$$

$$\delta_{contour} = 2\pi \times \frac{I_3}{255} \quad (3)$$

$$\delta_{agent}(t) = \delta_{local}(t) + \alpha(\delta_{contour} - \delta_{local}(t)) \quad (4)$$

Rings are validated when agents have gone over a loop and find again their initial position.

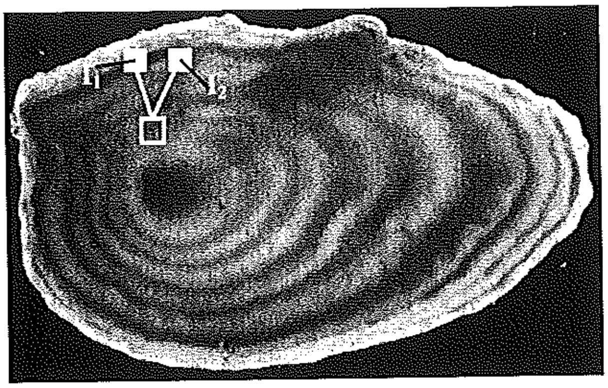

Figure 5 : Agent sensors on the grey level image

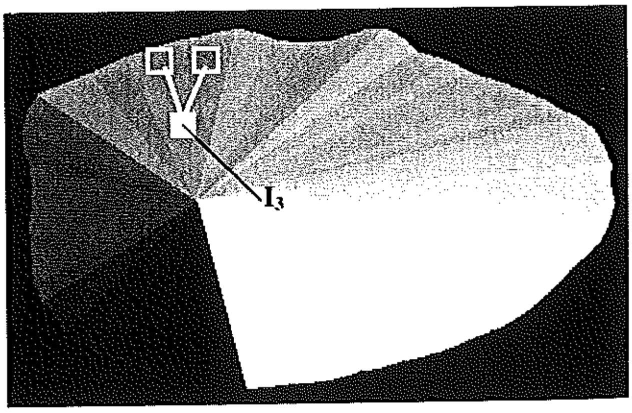

Figure 6 : Sensor of the same agent on the orientation image

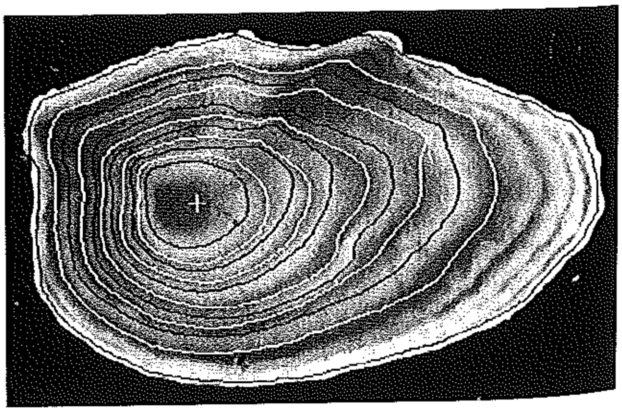

Figure 7 : Rings detected by directed agents

C. Reconstructed path

In this approach, agents are also aware of the external contour's orientation, but their direction only depends on the grey levels of the otolith image. Agents record their path in an image by increasing the grey level of a pixel each time they go on it (Figure 8). At the end of the processing, this image will be thresholded to keep the most frequented paths. During the processing the agents also record their path in another image, whenever the local orientation is similar to the one of the external contour (they know this orientation using the image created in step d. §3.A.). A logical AND between this image and the thresholded path image will allow to obtain a map of growth rings edges, which correspond to the most frequented and best oriented agents paths (Figure 9). This map will be used to begin rings reconstruction, starting from the smallest one around the nucleus, and using a method similar to active contours. The shape of the current ring is inflated, by translating each point of the shape using a vector, which direction is similar with the one of a line going through the nucleus and this point (Figure 10). Growth stops when the correspondence between the inflated shape and the pixels of the edge map is maximal.

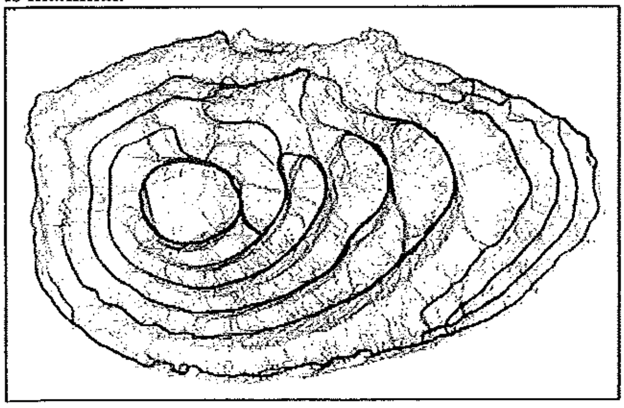

Figure 8 : Light agents path on the image Figure 3

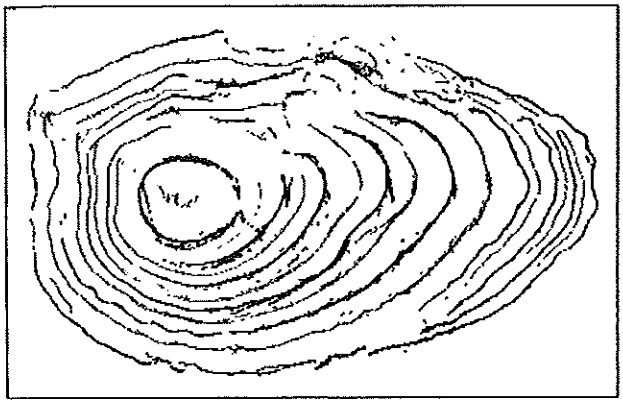

Figure 9 : Most frequented and best oriented agents paths

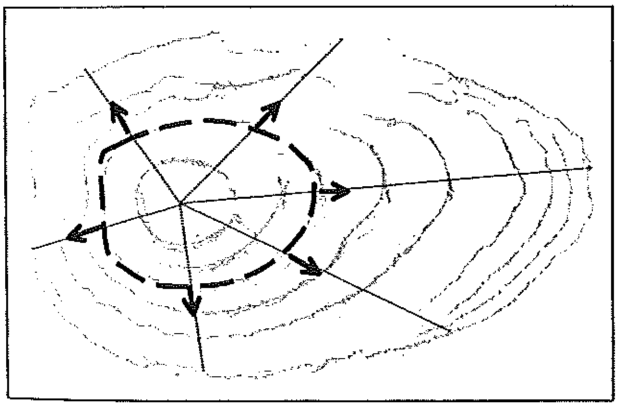

Figure 10 : Inflation of the current ring for next ring detection

By counting the number of rings detected with the first or the second method, the age of the fish can be estimated.

Figure 11 illustrates the result of the method on an eight year old individual.

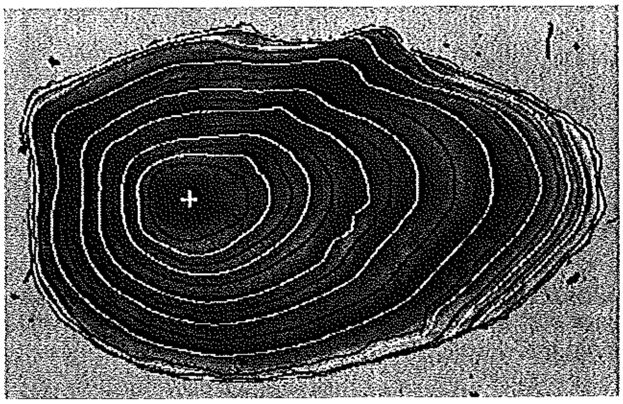

Figure 11 : Rings detected with reconstructed path method

D Agents parameters adjustment

The width of rings appearing during the fish growth decreases when fish gets older. Therefore the size of agents sensors need to be adapted in order to detect large rings near the nucleus and thin rings near the edge. Rings width can be approximated according to their position in the otolith using a growth model, but variability is very important between individuals. Nevertheless the size of the otolith allows to estimate roughly the number and the width of rings. Knowing the position of the nucleus and the co-ordinates of the otolith edge, it is possible to create an image which will inform the agent about its relative position on the otolith (Figure 12). In this image the grey level increases from 0 on the nucleus to 255 at the otolith edge. The agents will be provided with one sensor on this image. As the grey level of this image increases from the nucleus to the edge, the intensity read by the sensor will allow the agent to locate itself in the image. As it was shown in [4] and [5], agents can detect edges of different widths with the same parameters. Thus when otoliths are young, which means that rings width is quite constant, agents can detect all rings with only one set of parameters, but for older individuals they have to reduce the length of their sensors to improve thin rings detection, which appear at the end of the fish life. When the size of the main growth axis corresponds to an old individual, the image of the localisation (Figure 12) will be divided in two sectors. The contour of the central area is defined by the points of the external shape reduced by an homothety with a factor of ¾. These points are also defined by the pixels having the same grey level G_{max} in this image. According to the grey level G an agent reads in this image, the length L of its sensors will be determined as follows :

$$\text{if } G < G_{max} \text{ then } L = L_{max}$$
$$\text{else } L = L_{min}$$

For our tests with plaice otolith images, the optimal values for L_{max} and L_{min} were respectively 8 and 2 pixels.

The localisation image also allows to compute the coefficient α described in section 3.B., as follows :

$\alpha = G/255$.

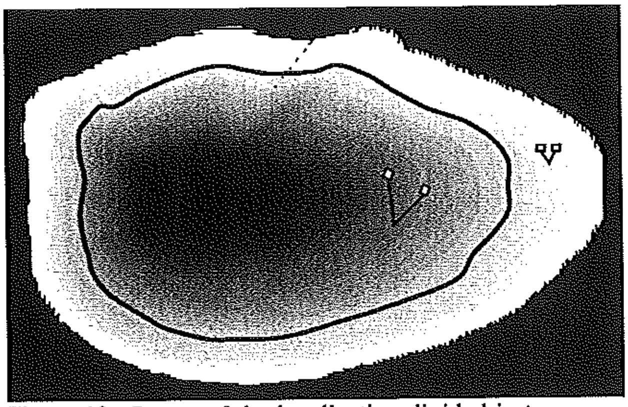

Figure 12 : Image of the localisation divided in two areas for old individuals; size of the agents sensors in each case.

4. RESULTS AND DISCUSSION

A. *Automatic nucleus detection*

The nucleus detection method has been tested by comparing the position of the nucleus automatically detected and the one of the nucleus detected by a human expert on a sample of 119 plaice otolith images. As the real position of the nucleus is unknown, we can only measure the distance between these two estimations to evaluate the method. We obtain a quite good detection of the nucleus with a 7.86 pixels mean distance between automatic and manual detection, with a 512*512 resolution (Figure 13). The images for which the detection error is quite important are very bad contrasted and the first ring is very difficult to distinguish.

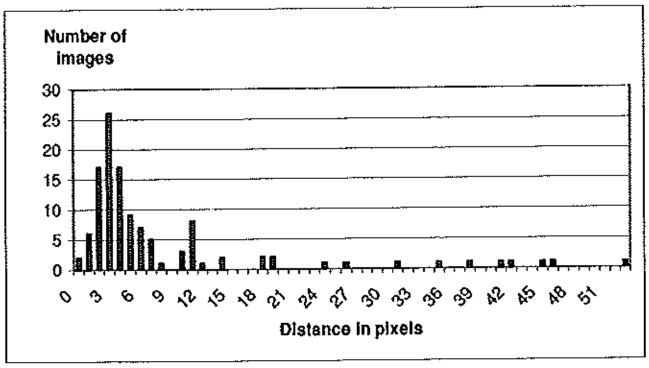

Figure 13 : Distribution of the distance between the nucleus detected automatically and the nucleus detected by a human reader

B. *Age estimation methods*

The two methods have been evaluated by comparing the age automatically estimated on a sample of 119 plaice otolith images, from age group 1 to 13, with the age estimated on these images by a human reader. The image on Figure 2 represents the rings detected on an eight year old plaice otolith by free agents, which means that the agents have no high level information about the image they are processing. They only try to validate loops by searching for local intensity extremes. Therefore the bad contrasted or indistinct rings are not detected.

As agents are aware of the shape of the otolith, in the "directed agents" method, they can go forward in areas where contrast between light and dark rings is very bad. The number of detected rings has been improved with this method and fanciful loops, that can be detected by free agents, have been avoided (Figure 7). This method is nevertheless causing a frequent under-estimation of the age of old fishes, because the condition required to validate a ring – when an agent finds again its initial position – is not easily satisfied when rings are distinct only in a restricted area of the image (Figure 7, Figure 14).

The "reconstructed path " method allows to improve the detection of these last rings, by using the local detection of edges achieved by agents, and guiding the reconstruction of a ring using the shape of the previous one. The percentage of good age estimation is thus better for old individuals (Figure 11, Figure 15).

The methods proposed in this paper give better results than those obtained with a mono-dimensional method applied on otolith images, which is described in [11]. This method consists in searching intensity extremes on an image profile starting from the nucleus to the otolith edge. Therefore the structures continuity is not taken into account.

The "reconstructed path" method also presents better results than those presented in [10] (deformable templates), mainly for old individuals because the shape of rings is more correctly detected. Otherwise the graph method [9] gives similar results with those of the "reconstructed path", but the latest is less time-consuming. Moreover the graph method, which requires a polar transformation of the image using the nucleus as the centre, cannot be applied to otoliths having several nuclei. Figure 16 illustrates the fact that the reconstructed path method can be used for processing more complex images such as pout otolith images.

Problems could appear when the co-ordinates of the first ring were not correctly determined by agents during the step b. (§ 3.A.b.), so that the nucleus co-ordinates were too far from those of the real nucleus.

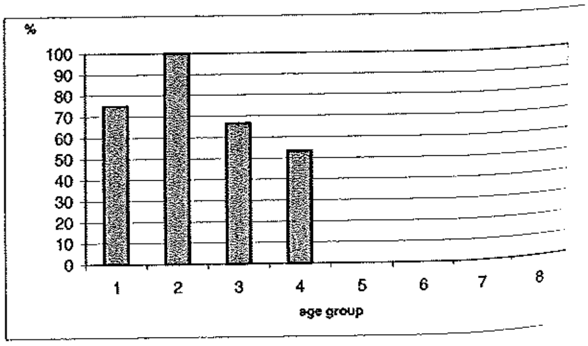

Figure 14 : Percentage of good age estimation for directed agents on otoliths from age group 1 to 8

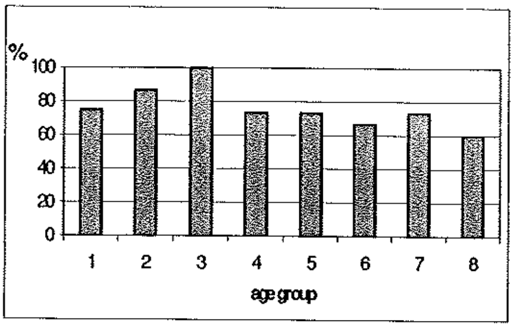

Figure 15 : Percentage of good age estimation for the reconstructed path on the same images

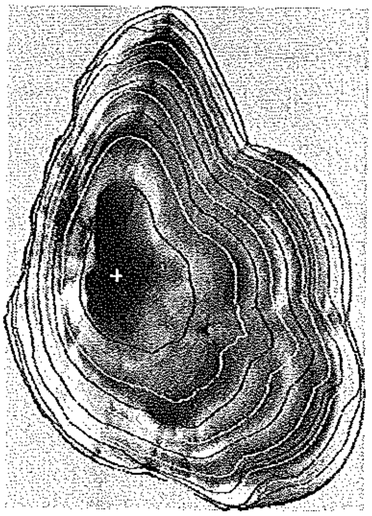

Figure 16 : Result of the reconstructed path method on a pout otolith image

5. CONCLUSION

We have developed a method to perceive continuity of contours in textured, noisy and low contrast images. Previous methods needed operator intervention to give the nucleus position whereas the pointing is automated here. The agents are able to detect local edges in the image, while perceiving their continuity by the way they move. This property is very interesting for processing otolith images, which are noisy and textured. Because they are too sensible to noise and texture, classical edge detection operators cannot be used with such images. Agents can also adapt locally the size of their sensors according to the ring width.

In the future we intend to find a new criterion for the agents to validate a ring, which should be more robust than the fact that the agents have to find again their initial position.

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